Thermal turbulence in the very stable boundary layer: sodar observations at Dome C, Antarctica

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The knowledge of the properties of the atmospheric turbulence is important to understand the influence of the atmospheric surface layer thermal turbulence on distortion of astronomical images and the propagation of electromagnetic waves for telecommunication purposes.
During a campaign carried out at Concordia station (Dome C, East Antarctica) in winter 2012, an experiment was made to determine the behaviour of the atmospheric turbulence in the first hundred meters above the surface. The surface layer in the interior of Antarctica during winter is extremely stably stratified with the temperature inversion strength reaching 20-35 C. The behaviour of the thermal turbulence was observed and measured both remotely, using a specially designed high-resolution sodar, and in situ by a sonic anemometer.

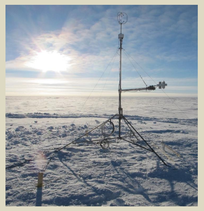
INSTRUMENTATION

SLM **SODAR** – special surface layer high-resolution sodar measures vertical profiles of the strength of thermal turbulence from ~ 2 m with a step of ~ 1 m

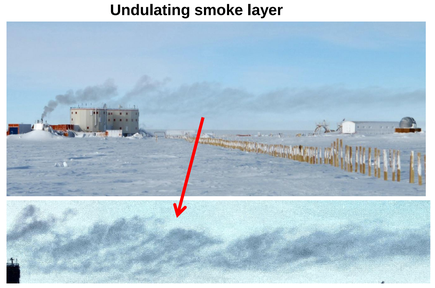
AWS Milos520 RMO

Radiosonde RS92-SGPL

Ultrasonic thermoanemometer USA-1 Metek
Net Radiometer CNR1 Kipp & Zonen



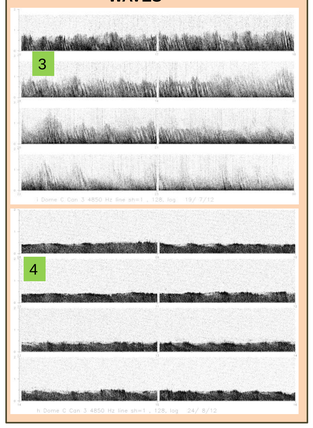
Undulating smoke layer



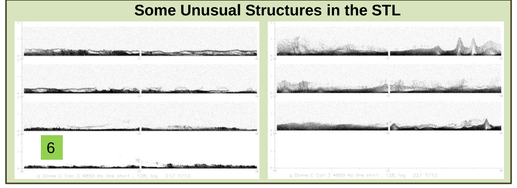
Mist within the STL

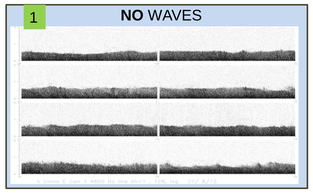
Examples of **long-living** Surface-based Turbulent Layers with undulating and homogeneous internal structure

WAVES

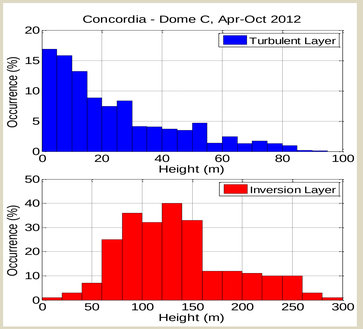


Some Unusual Structures in the STL





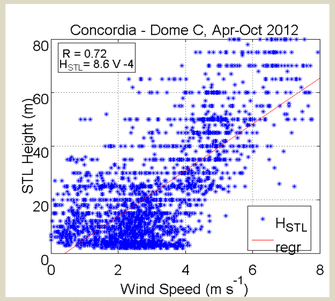
Histograms of Depth of the Surface Turbulent Layer (from sodar) and Inversion Layer (from Radiosonde)



Heights of Surface Turbulent Layer and Inversion Layer averaged over Apr-Oct 2012

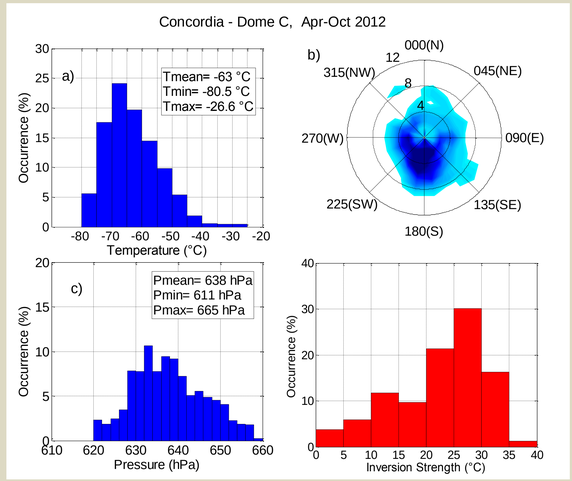
Heigth (m)	Mean (m)	Median (m)	Std (m)
Turbulent Layer	23	16	20
Inversion Layer	133	125	63

Surface-based Turbulent Layer occupies only the lowest 10-20% of the whole inversion layer

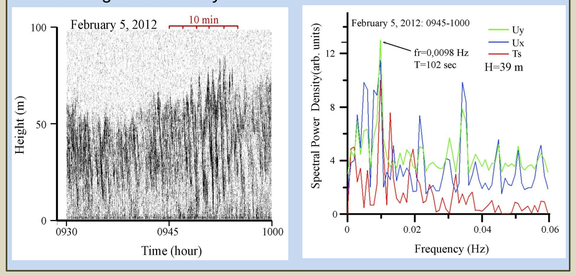


Height of Surface-based Turbulent Layer increases with Wind Speed

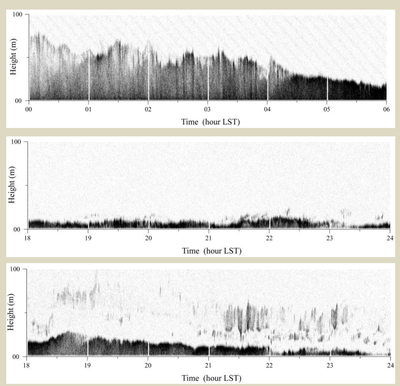
Meteorological conditions in winter



Spectra of wind components from sonic measurements during wave activity

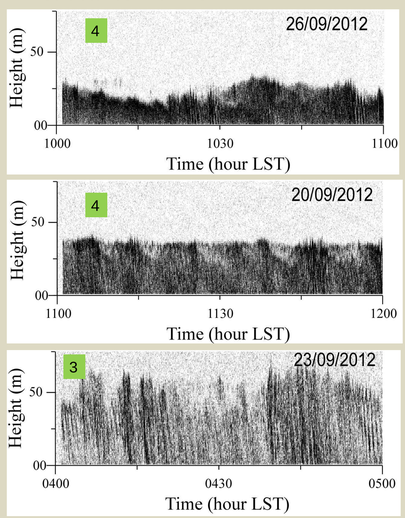


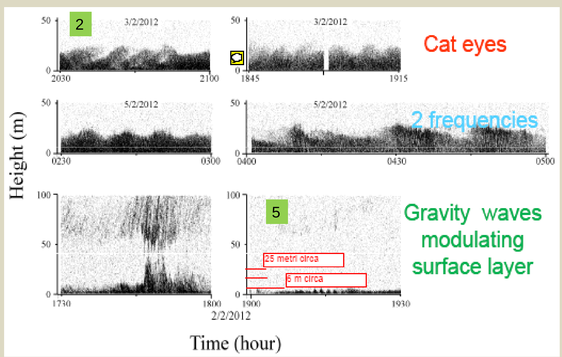
Some typical cross-section patterns of the Surface–based Turbulent Layer (STL) depicted by sodargrams



Greyscale intensity is proportional to the strength of thermal optically-active turbulence characterised by the structure refraction index parameter C_n^2

Examples of undulating internal structures within STL





The observed STL types can be subdivided into several principal groups according to their heights and internal structure.
1) 'High' of 10-50 m with uniform homogenous internal structure
2) 'High' of 10-50 m with wavy internal structure of cat-eye form with periods of 60-300 s
3) 'High' of > 50 m with regular wavy internal structure with periods of 1-2 minutes through the whole depth
4) 'High' of 10-50 m with periodical (of ~ 10 minutes) alternation of wave trains (with internal periods of ~ 20-30 s and duration of ~ 4-5 minutes) and zones with uniform homogenous internal structure.
5) 'Shallow' of < 10 m with the wavy internal sub-layer.
6) 'Shallow' of < 10 m without any visible regularity of the internal structure.

Some other forms of STL are also observed

Application for Astronomy

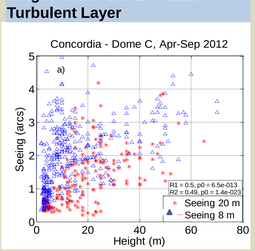
The intensity of thermal turbulence measured with a sodar is characterized by the ***temperature structure parameter*** C_T^2.

The intensity of optically-active turbulence is described by the ***refraction index structure parameter*** C_n^2.

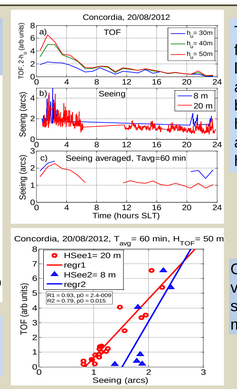
These parameters are connected directly $C_n^2(h) = B(p, T)\, C_T^2(h)$. The coefficient $B(p, T) = (79.2 \cdot 10^{-6}\, pT^{-2})^2$, where p is the air pressure in mb, T is the absolute temperature in K.

The ***Turbulent Optical Factor*** **(TOF)** $TOF = \int C_n^2(h)dh$ evaluates a degree of degradation of a stellar image by turbulence localized in the layer at altitudes from h_1 to h_2.

Correlation between Seeing and Height of the Surface-based Turbulent Layer



The best image quality (lowest seeing values) are observed for lower heights of STL



Time series of turbulent optical factor measured by sodar for 3 layes (top panel – 1-hour average) and seeing measured by optical method DIMM at 2 heights (middle panel – 2-min average, bottom panel – 1-hour average)

Correlation between TOF values measured by sodar and seeing measured by optical method DIMM at 2 heights

CONCLUSIONS

In spite of the strong static stability due to the strong temperature inversion, the considerable thermal turbulence occurs sometimes and extends up to several tens of metres. The behaviour of the thermal turbulence was observed and measured both remotely using a specially designed high-resolution sodar, and in situ with a sonic anemometers. Typical patterns of the cross-section of thermal turbulence determined by sodar are presented. Statistics of the Surface-based Turbulent Layer (STL) depth and the inversion height are presented. The depth of the STL increases with wind speed. Surface-based Turbulent Layer occupies only the lowest 10-20% of the whole inversion layer.
Wave activity within the turbulent layer was observed during the major part of the time. The characteristics of the wavy structures is the main subject of the further studies.

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